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Valve: Short report

Anterior Pericardial Patch Augmentation Repair and Neochord Implantation for Rheumatic Mitral Valves

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ABSTRACT

BACKGROUND The objective of this study was to biomechanically evaluate anterior pericardial patch augmentation repair and the modified technique using neochord implantation in an ex vivo rheumatic mitral valve (RMV) model.

METHODS Thermal treatment to the leaflets and chordae and commissure fusion were performed on 4 healthy porcine mitral valves to generate the ex vivo RMV model. Repair was performed by conducting commissural release and anterior pericardial patch augmentation, with or without implantation of 2 neochordae. Hemodynamic, echocardiography, native chordal forces, and high-speed videography data were collected.

RESULTS Compared with baseline, the RMV model successfully generated mitral regurgitation with a regurgitant fraction (RF) of 20.3% ± 9.4% ($P = .03$) and decreased coaptation height of 0.5 ± 0.3 cm ($P = .004$). Compared with the RMV model, patch augmentation repair improved regurgitation with an RF of 3.3% ± 1.7% ($P = .05$) and coaptation height of 1.4 ± 0.3 cm ($P = .003$); the rates of change of primary (0.1 ± 0.4 N/s vs 2.0 ± 1. 2 N/s; $P = .05$) and secondary (3.1 ± 1.7 N/s vs 5.3 ± 0.9 N/s; $P = .002$) chordal forces were also decreased. The modified technique enhanced valve hemodynamics by improving RF (3.4% ± 2.2%; $P = .12$) and coaptation height (1.8 ± 0.3 cm; $P = .09$) to levels similar to those from baseline. Compared with patch augmentation repair, the rates of change of force of secondary chordae were further decreased (2.1 ± 1.3 N/s; $P = .05$).

CONCLUSIONS Anterior pericardial patch augmentation was effective in repairing RMV by re-establishing coaptation while reducing mean gradient. The modified technique further improved valve hemodynamics and native chordal forces. This study provides biomechanical evidence in favor of anterior pericardial patch augmentation repair and may direct further repair modifications to improve clinical outcomes.

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Rheumatic mitral valve (RMV) disease represents an important cause of mitral regurgitation (MR) and mitral stenosis in endemic countries.[1] RMV is commonly manifested with leaflet shortening, valve thickening with calcium deposition, and commissure fusion, resulting in restricted leaflet motion and improper leaflet coaptation. Although valve replacement is the standard treatment, mitral valve (MV) repair is generally favored for severe primary MR.[2,3] However, in the case of RMV with valvulitis, repair may be associated with decreased durability and an increased risk of reoperation.[4] Adjunctive repair

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techniques, such as anterior pericardial patch augmentation repair (APAR), have been described and can successfully repair RMVs in select patients.[5] This repair technique uses autologous or bovine pericardium to re-establish proper leaflet coaptation. However, the biomechanics underlying the anterior patch augmentation repair for RMV are not well understood.

Synthetic neochord implantation repair with expanded polytetrafluoroethylene sutures is commonly used in MV repairs for MR.[6] These neochordae can re-create proper coaptation by reanchoring the leading edge of a prolapsed segment to the corresponding papillary muscle. Excellent long-term outcomes have been reported with this repair technique.[6] In previous biomechanical ex vivo studies, neochord repair was found to generate excellent valvular hemodynamics while lowering native chordal forces.[7]

In this study, we sought to biomechanically evaluate an ex vivo RMV model after APAR and to assess the impact of additional neochord repair as a modified technique on valvular hemodynamics and biomechanics.

IN SHORT

- Anterior pericardial patch augmentation is effective for rheumatic mitral valve repair to eliminate mitral regurgitation and to increase opening orifice area.
- The modified technique with neochord implantation through the anterior pericardial patch simulates the addition of secondary chordae and may further enhance valve hemodynamics, coaptation height, and chordal force profiles.

MATERIAL AND METHODS

SAMPLE PREPARATION AND STUDY DESIGN. Healthy porcine hearts (n = 4) were obtained from a meat abattoir (Animal Technologies). MV explantation and mounting were described previously.[8] After baseline data collection, the MV was retrieved from the ex vivo heart simulator. Without explantation of the MV from the mitral mount, thermal treatment was applied to the MV leaflets and chordae by carefully exposing the MV apparatus, and not the papillary muscles, to 100 °C deionized water for 60 seconds.[8] Commissure fusion was then performed by using interrupted CV-6 sutures on the ventricular side of the MV leaflets. This ex vivo RMV model was generated (Figure 1) and placed in the heart simulator for data collection.

To repair the RMV, commissure fusion was first released. Next, an incision was made along the anterior portion of the annulus to detach the anterior leaflet from the mitral annulus (Supplemental Figure A). The commissures and native chordae were kept intact. Next, an oval bovine pericardial patch sized by an MV sizer was sutured onto the native anterior leaflet with 4-0 polypropylene sutures in a running fashion (Supplemental Figures B-D). After APAR, data were collected. Lastly, to evaluate the modified technique with artificial neochord implantation, 2 CV-5 sutures were placed through each papillary muscle and through the pericardial patch. These sutures were tied down to the level of the MV annulus. The last round of measurements was taken to complete the study. For each sample, the baseline condition served as its own control. The same valve was treated to generate the RMV model, followed by 2 repair techniques in order: APAR and the modified repair. For detailed information on the ex vivo left heart simulator, chordal force measurement setup, and echocardiography data collection, refer to the Supplementary Methods.

SAMPLE SIZE CALCULATION AND STATISTICAL ANALYSIS. To achieve a power of 80% and a significance of .05, a sample size of 4 is required to detect a mean difference of 17% between 2 groups with an expected SD of 8%. These numbers were extracted from our prior studies.[7,8] Continuous variables were reported as mean ± SD unless specified otherwise. To compare differences between different conditions, repeated measures analysis of variance test was performed with post hoc adjustment. Statistical significance was defined at $P < .05$ for all tests. P values reported in the Supplemental Table were calculated from repeated measures analysis of variance, whereas P values reported in the text were calculated from post hoc adjustment.

RESULTS

The ex vivo RMV model was successfully generated after thermal treatment to the MV leaflets and chordae and fusing the commissures (Figure 2). Thickened, shortened leaflets with restricted leaflet motion and significantly reduced MV opening orifice area were observed (Videos 1, 2). There was also minimal leaflet coaptation in the RMV model. APAR successfully lengthened the anterior MV leaflet and re-established coaptation (Figure 2; Video 3). The MV opening orifice area was also enlarged with less restricted leaflet motion. However, the augmented anterior leaflet had a mild degree of prolapse. The modified repair technique with neochord implantation onto the pericardial patch effectively reduced the prolapse observed from the pericardial patch and further reinforced the coaptation without affecting MV opening orifice area or leaflet motion (Figure 2; Video 4).

In terms of valvular hemodynamics (Figure 3), the baseline regurgitant fraction (RF) was 1.1% ± 1.5% with leaflet coaptation height of 1.6 ± 0.3 cm. Mean

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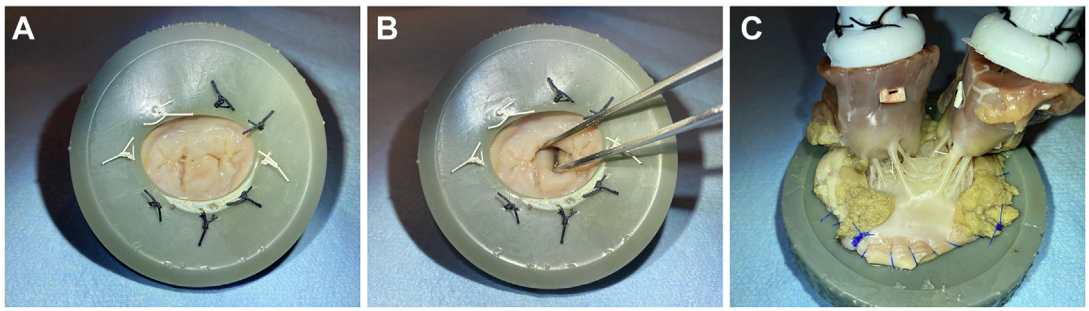

FIGURE 1 An exemplary ex vivo rheumatic mitral valve (RMV) model. (A) An RMV after thermal treatment and commissure fusion implanted in a 3-dimensional–printed mitral mount. Note the thickened, retracted mitral leaflets. (B) A pair of forceps placed across the RMV to demonstrate significantly reduced mitral valve opening orifice. (C) Ventricular view of the RMV showing thickened, shortened native chordae after thermal treatment.

transvalvular gradient was 2.8 ± 1.0 mm Hg. Compared with baseline, the RMV model successfully generated MR with an RF of 20.3% ± 9.4% (P = .03) with decreased coaptation height of 0.5 ± 0.3 cm (P = .004) and increased mean gradient of 14.3 ± 5.6 mm Hg (P = .02). After APAR, MR was reduced to an RF of 3.3% ± 1.7% (P = .05) with increased coaptation height of 1.4 ± 0.3 cm (P = .003) and decreased mean gradient of 6.0 ± 2.9 mm Hg (P = .008). However, RF after APAR was higher compared with that from baseline (P = .05), and the leaflet coaptation height after APAR was still lower than that from baseline (P = .03). The modified technique further optimized valve hemodynamics by improving RF (3.4% ± 2.2%), coaptation height (1.8 ± 0.3 cm), and mean gradient (6.3 ± 2.2 mm Hg) to levels similar to those measured from baseline (P = .12, P = .09, and P = .07, respectively). A summary of hemodynamic data is shown in the Supplemental Table.

In the RMV model, peak forces of the primary and secondary chordae were 0.2 ± 0.1 N and 0.5 ± 0.1 N, respectively, and rates of change of force were 2.0 ± 1.2 N/s and 5.3 ± 0.9 N/s, respectively (Figure 4). After APAR, peak forces of the primary and secondary chordae were decreased to 0.1 ± 0.0 N (P = .04) and 0.2 ± 0.2 N (P = .01), respectively. The rates of change of force of both the primary and secondary chordae were also decreased to 1.0 ± 0.4 N/s (P = .05) and 3.1 ± 1.7 N/s (P = .002), respectively. Further repair using the modified technique did not change the peak forces on the primary chordae (0.1 ± 0.1 N; P = .88) or secondary chordae (0.2 ± 0.1 N; P = .23) compared with APAR. However, the peak forces on the primary and secondary chordae were lower than those measured from RMV (P = .04 and P = .002). Compared with APAR, the modified technique decreased the rate of change of force on secondary chordae (2.1 ± 1.3 N/s; P = .05), but no difference was observed in the rate of change of force on primary chordae (1.0 ± 0.7 N/s; P = .78). The modified technique was associated with lower rates of change of force of the secondary chordae (P = .0002) but not of the primary chordae (P = .06) compared with RMV.

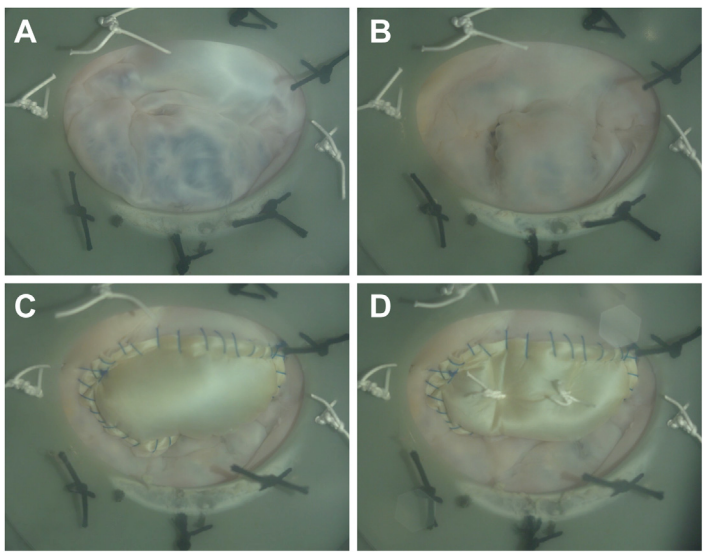

FIGURE 2 Exemplary en face view of the same mitral valve at (A) baseline, (B) rheumatic mitral valve model, (C) after anterior pericardial patch augmentation repair, and (D) after the modified repair technique with neochord implantation. The rheumatic mitral valve model demonstrated thickened, shortened leaflets. Anterior pericardial patch augmentation repair successfully extended the anterior leaflet to allow proper leaflet coaptation. A mild degree of prolapse of the augmented anterior leaflet was further reduced after use of the modified technique.

COMMENT

In this study, we successfully demonstrated the use of an ex vivo RMV model. We showed that this ex vivo model effectively mimicked clinical disease with

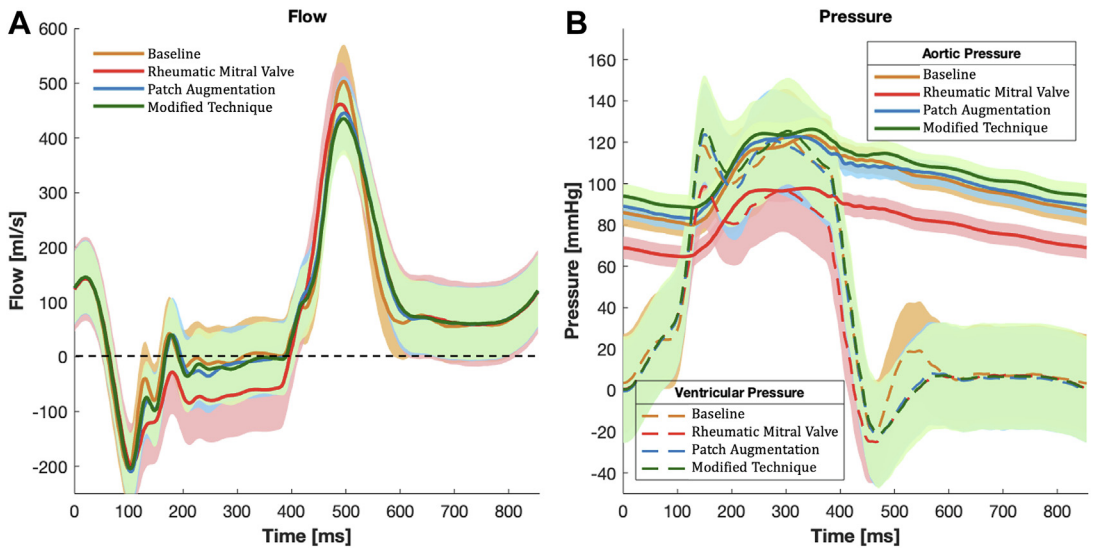

FIGURE 3 Transmitral (A) flow and (B) pressure tracings measured from baseline, from the rheumatic mitral valve, after anterior pericardial patch augmentation repair, and after the modified repair technique with neochord implantation. Note the flow reversal in systole in the rheumatic mitral valve model, suggesting mitral regurgitation. After anterior pericardial patch augmentation repair and the modified repair with neochord implantation, mitral regurgitation was eliminated. Shaded areas represent standard deviations.

correlated quantitative findings, confirming the validity of our model. Pericardial patch augmentation repair for the MV has been previously described to surgically lengthen the severely shortened and retracted MV leaflet to re-establish coaptation.[6] The ability to preserve the MV apparatus can prevent adverse remodeling of the left ventricle and has been shown to enhance and maintain left ventricular functions.[9] Therefore, MV

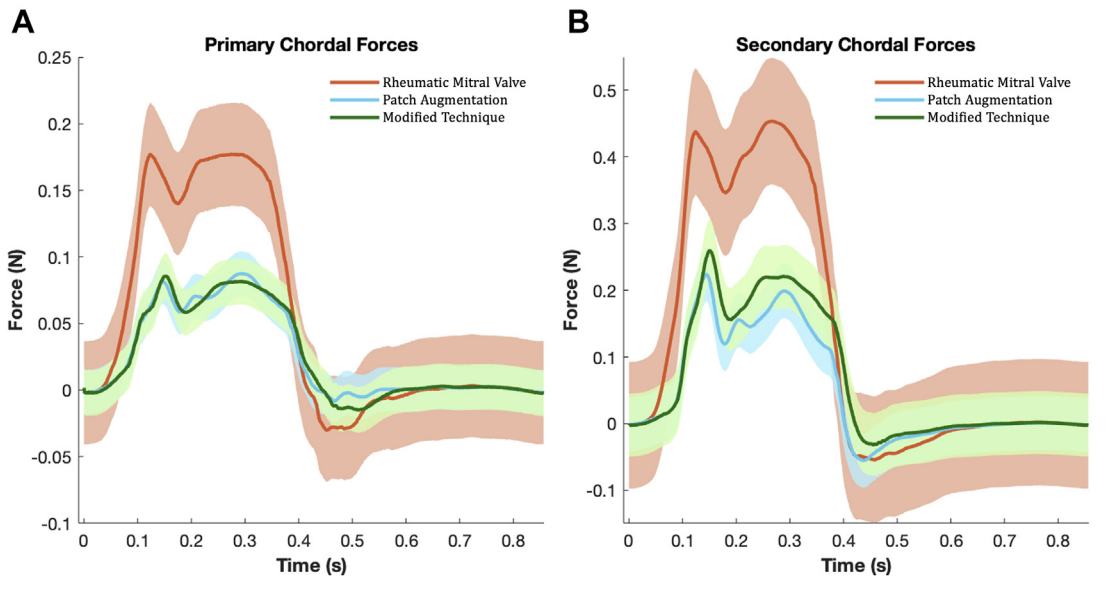

FIGURE 4 Averaged chordal force tracings during the course of a complete cardiac cycle from (A) primary chordae and (B) secondary chordae from the rheumatic mitral valve model, after repair using the anterior pericardial patch augmentation, and after the modified repair using neochord implantation. Note the significantly decreased forces after repair compared with the rheumatic mitral valve model. The shaded areas represent standard deviation.

repair, if at all possible, should be considered for RMV patients, especially given excellent outcomes reported from several studies. In this study, we evaluated the hemodynamics and biomechanics with use of the APAR technique and demonstrated that MR can be successfully eliminated with significantly decreased mitral stenosis. Reassuringly, we also demonstrated that both primary and secondary chordal force profiles were optimized after the APAR. We believe that the re-establishment of leaflet coaptation minimized forces imparted on the native chordae.

The motivation of evaluating the modified repair technique with neochord implantation was based on previous ex vivo biomechanical studies that demonstrated lowered native chordal force profiles with artificial neochord implantation repair.[7] Furthermore, prior Instron tensile testing data demonstrate that higher numbers of interrupted neochordae are associated with lower neochord forces.[10] The pericardial patch implanted on the anterior leaflet does not come with chordae, whereas in nature, most of the leaflet surfaces are supported by secondary chordae anchored to papillary muscles.[11] These secondary chordae not only prevent leaflet prolapse but also bear most of the forces in systole. We confirmed our hypothesis that by implanting additional artificial secondary neochordae directly through the pericardial patch, forces on the native chordae can be further lowered, and the mild anterior leaflet prolapse in the patch area can be eliminated.

One area of refinement for this study is to simulate the long-term changes in RMV with calcification and papillary muscle pathologic changes, such as fusion and displacement. This may be further explored ex vivo.[12] However, the rapid generation of our ex vivo RMV model with very close clinical relevance is a significant advantage of our model, allowing fast, iterative assessment of various repair techniques. Further efforts will focus on exploring the possibility of generating a model without the need to remove the MV and reimplant chordal force sensors from the simulator. Lastly, to allow direct translation of our findings to clinical practice, large animal in vivo validation studies and verification experiments using human tissues may be performed to confirm the biomechanics of both repair techniques.

The Supplemental Material can be viewed in the online version of this article [https://doi.org/10.1016/j.atssr.2023.02.006] on http://www.annalsthoracicsurgery.org.

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DISCLOSURES

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